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Time-of-flight neutron transmission imaging of martensite transformation in bent plates of a Fe-25Ni-0.4C alloy

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Abstract

The influences of bending deformation and subsequent subzero treatment on the martensite transformation behaviors in a metastable austenitic alloy Fe−25 wt.% Ni−0.4 wt.% C were investigated by the time-of-flight (TOF) neutron Bragg-edge transmission (BET) imaging method. Two-dimensional (2D) maps of martensite phase volume fractions and texture variations due to residual stress and lowering the temperature of the bent samples before and after subzero treatment were obtained by Bragg-edge spectral analysis. The obtained phase volume fractions were quantitatively compared with those determined by neutron diffraction.

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Keywords: metastable austenitic steel; martensite transformation; Bragg-edge; neutron imaging; neutron diffraction

1. Introduction

The martensitic transformation followed by appropriate tempering treatment is the most effective method to obtain steel products with high strength and high toughness. Martensite transformation in steel is affected by many

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parameters, such as the chemical composition, the external stress, the residual strain and the ambient temperature (Tomota et al. 2006 and Zhang et al. 2015). A TRIP (Transformation-Induced Plasticity) phenomenon refers to stress induced martensitic transformation to promote plasticity, and the TRIP steel has already been widely used in the automotive industry for the production of car body elements. Bending is one of the most frequently used in the sheet-forming operations in the automotive industry to produce structural and safety parts. The materials during bending involve plastic deformation combined with tension and compression simultaneously (Oliver et al. 2002 and Réche et al. 2012). In our previous work (Su et al. 2016), time-of-flight (TOF) neutron Bragg-edge transmission (BET) imaging measurements were performed for plastically bent plates consisting of a ferritic steel and a duplex stainless steel. The microstructure and residual elastic strain distributions of the bent steel plates were evaluated for the cross sections of the bent plates. The phase volume fractions of constituent phases in the duplex stainless steel sample were successfully determined using the obtained projection data of the atomic number density. In the present study, the effect of residual stress due to bending deformation and the effect of temperature on the body centered tetragonal (BCT) structure martensite transformation from face-centered cubic (FCC) structure austenite were investigated by the BET imaging method. In addition, the evolution of phase volume fraction and texture of the same samples were also analyzed by the well-established neutron diffraction method.

2. Experimental Procedures

In this study, a metastable austenitic alloy with the composition of Fe−25Ni−0.4C (by wt.%) was used. The sample preparation processes are shown in Fig. 1. First, a plastic prestrain was applied to the 13 × 12 × 250 mm3 samples at room temperature (RT) via three-point bending using a universal machine. Next, the thicknesses of the bent samples were machined from ca. 12 mm to 6 mm or 2.5 mm. Finally, a subzero treatment was applied to the samples to induce martensite structure. The start temperature of martensite transformation on cooling (Ms) of the Fe−25Ni−0.4C alloy was previously reported to be about −60℃ (Maki et al. 1980). The subzero treatment was then performed by immersing the bent samples in a thermally insulated bath of liquid nitrogen and alcohol, where the temperature of the bath was monitored by an ultra-low temperature digital thermometer, to ensure approximately isothermal conditions, one at −70℃ and one at −90℃, for 1800 s each, as illustrated in Fig. 1(b). The specific temperatures were controlled by pouring the liquid nitrogen. The transformation of the steel microstructure from austenite to the stronger and harder martensitic structure was expected during the bending deformation and subzero treatment processes. Thus, three kinds of bent samples were measured: sample_RT, sample_−70 ℃ and sample_−90℃, referring to before subzero treatment, subzero treatment at −70℃ and subzero treatment at −90℃, with thickness of 6 mm, 6 mm and 2.5 mm, respectively.

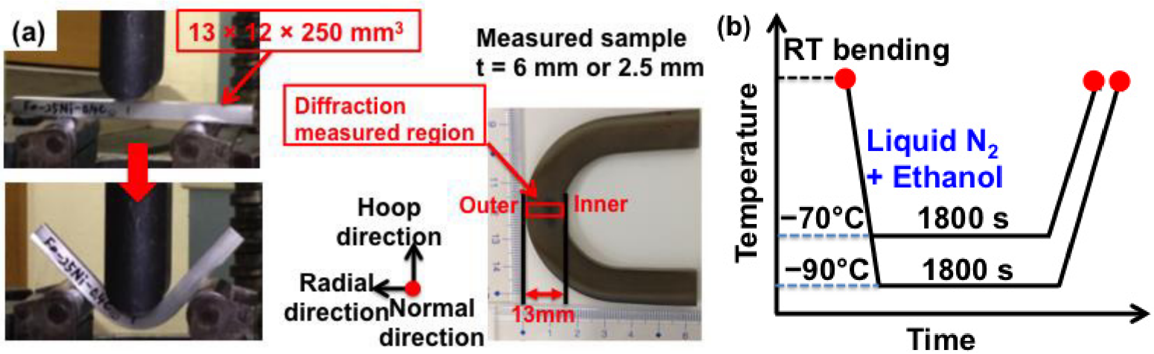

Fig. 1. Sample preparation process: (a) three-point bending and definition of coordinate system for diffraction and BET measurements and (b) schematic illustration of subzero treatment.

Pulsed neutron imaging experiments were performed at BL22 RADEN (Kiyanagi et al. 2013) and BL10 NOBURU (Oikawa et al. 2008) of the MLF/J-PARC with 200 kW proton beam power. A 100 × 100 mm^2 area gas